A POSSIBLE FISH-KILLING YELLOW TIDE IN CALIFORNIA WATERS

James B. Lackey and K. A. Clendenning

Red tides are not uncommon along the California coast in the vicinity of San Diego. These discolorations of the water seem to be due principally to dinoflagellates, although diatom blooms could as easily impart the reddish color to the water, and probably do at times. In the summer of 1959, a red tide was reported from Baja California which proved to be due to a ciliate, *Mesodinium rubrum.* Little attention is attracted to blooms of green organisms. They rarely kill fish. A green euglenid, probably *Eutreptia,* was supposed to have caused a fish kill off the Malabar coast of India (Hornell, 1917). Green water caused by *Prymnesium,* not green itself, has likewise been incriminated in fish kills.

The literature on fish kills caused by, or associated with, blooms of microorganisms is quite voluminous. Hutton (1956) has reviewed the published work dealing with the notorious Florida Gulf coast organism, *Gymnodinium breve,* which may produce local kills, or may affect an area 200 miles long and 30 miles wide (Lackey and Hynes, 1955) in water from 3 feet to 50 feet deep. Many other references could be cited relative to blooms in many parts of the world (U. S. Fish and Wildlife Service, 1961), but there have been few instances of reported fish kills along the California coast.

Few of the recorded cases have been sufficiently studied to identify the killing substances or mechanism. In the case of *Gymnodinium breve,* a neurotoxin is supposed to be the lethal agent (Collier, personal communication, 1963), but is still not isolated. But this is one of the few cases wherein a non-parasitic microorganism has definitely been incriminated. Industrial wastes have accounted for the majority of fresh water fish kills (loc. cit.) with agricultural poisons second. Generally oxygen depletion is suspected when a kill occurs, but since the suspected killer is frequently a photosynthetic organism, the case is not often proved unless an investigation is made while the kill is in progress. Barlow and Myren (1961), discussing the oxygen resources of tidal waters, found that the oxygen consumption was greater than its production by photosynthesis in the Forge River, a tidal stream, at a time when the phytoplankton population was near its zenith. If this is a com-

mon occurrence, it could solve more than one dilemma in regard to fish kills, and definitely incriminate oxygen depletion as a mechanism, and not necessarily the production of a toxin by a specific organism.

The Fish Kill in Mission Bay

In July, 1961, a minor fish kill was reported in Mission Bay, California. The first dead fish were noticed at Asher Cove, a bathing beach; subsequently it was learned that some fish had died across the Bay in De Anza Cove, also a bathing beach. A variety of fish were killed, but not in large numbers did deaths occur except during 24 hours. Nevertheless, considerable talk and some apprehension was aroused; the tendency was to ascribe it to sewage contamination, and the health authorities were asked repeatedly if the beaches were safe. A quick check showed no chance of sewage having entered the Bay.

Microbiota of the Kill Area

While the kill was still in progress one of us (Clendenning), made a trip to the area and secured water samples to determine what organisms were present. These were refrigerated and examined the following day. The organisms were examined alive, after concentrating by centrifuging for 5 minutes at 2200 rpm. A Zeiss microscope with magnifications of 100X and 440X was used for counting which was done by the drop method (Am. Public Health Assn., 1960).

Table 1 shows the organisms present in Asher Cove at the time of the kill. There are several unusual features about this list. First, the number of species is only about one-half the number found in most of the summer samples in this area. Second, 13 of the 22 listed species are photosynthetic organisms (2307 per ml). While there were 1098 non-photosynthetic zooflagellates, and 10 ciliates per ml, they were mostly organisms about 5 to 12 microns in diameter. The outstanding fact is that 50.68 per cent of the total number of organisms were *Gymnodinium flavum*. The number found in Asher Cove was the highest encountered anywhere in the Bay or its environs this summer. This pale yellow dinoflagellate, about 40 microns in diameter, contains some melanic granules, but is not strongly colored. Nevertheless the water was pale yellow-brown in color, hence the term "yellow tide."

TABLE 1

Population of Asher Cove water, June 24, 1961, at time of fish kill

Organism		No/ml
Chlorococcales		
Green cells, mostly *Chlorella* sp.		120
Euglenophyceae		
Notosolenus sp.		6
Chrysophyceae		
Chrysococcus cinctus		60
Chrysochromulina spp.		60
Dinoflagellata		
Ceratium falcatiformis		51
Ceratium furca		27
Ceratium minuta		3
Dinophysis rotundatum		5
Gymnodinium flavum		1776
Gymnodinium minor		12
Gymnodinium variable		120
Gymnodinium spp.		84
Oxytoxum milneri		5
Peridinium divergens		1
Bacillariae (Diatoms)		
Detonula sp.		60
Nitzschia closterium		12
Zooflagellata		
Colorless cells (mostly *Oicomonas)*		480
Bodo sp.		12
Kephyrion ovum		600
Ciliata		
Stenosemella nivalis		1
Tintinnopsis everta		5
Tintinnopsis minuta		4
No. species ± 22	No. organisms/ml	3504

The organism was described by Kofoid and Swezy (1921) and at that time they described it as a bloom-former in the vicinity of La Jolla for a month in the summer of 1914. Apparently it has not been seen since, for very competent observers such as E. Balech failed to record its presence. Nevertheless, it was widespread around La Jolla in the summer of 1961. Table 2 gives a rough idea of this distribution. Number per ml fluctuated widely. Thus on the day following the fish kill, there were only 1104/ml in Asher Cove water, while across the sandspit there were 936/ml off the Mission Bay Yacht Club. It also showed wide variation in numbers at the surface and the 50-foot depth for a given station.

TABLE 2

Occurrence and numbers per ml of *Gymnodinium flavum* in San Diego waters, summer of 1961

Date	Sample from	Stations*											
		6	7	8	10	11	12	13	14	15	16	17	18
6–18	Top								0				
	Bottom								4				
6–21	Top	525											
	Bottom	471											
6–22	Top	336			0	0			0	0			
	Bottom	0			147	1			4	3			
6–28	Top	99	0										
	Bottom	105	2										
7–3	Top	12											
	Bottom	0											
7–10	Top	14							0	0	0	2	0
	Bottom	0							144	160	234	160	183
7–11	Top	631		0				0	0				
	Bottom	996		90				37	55				
7–12	Top	110	2676		411	156	12						
	Bottom	72	384		67	52	44						

*Stations

6—Ballast Point
7—Point Loma
8—Scripps Institution Pier
9—La Jolla Kelp Bed, North End
10—Convair Gantry
11—Sunset Cliffs Park
12—Ocean Beach
13—Bird Rocks
14—Mission Bay Entrance
15—Oceanarium
16—Terra del Fuego
17—Crescent Bay
18—Flood Control Channel

DISCUSSION

Evidence that *Gymnodinium flavum* is a fish killer is presumptive. First, the only fish kill brought to attention in two summers' work in this area occurred where the organism attained its maximum density. Second, it is difficult to envisage an oxygen depletion in the area where the kill occurred. There are several reasons why oxygen depletion may be ruled out. The areas are not contaminated by sewage or other wastes; the general area is shallow, subject to wave action, and good circulation, temperatures were not excessive; and the algae and protozoa present were not those characteristic of anaerobic situations, but rather, one of photosynthetic activity. While no dissolved oxygen tests were run, even if the kill might have been due to oxygen depletion, this is probably the organism having the largest biomass, so it would be indirectly the killer. Finally, much larger populations of rather similar organisms occurred in Mission Bay during the summer, but no fish died. It is therefore concluded that *Gymnodinium flavum* was the cause of the limited but general fish kill in Mission Bay in the summer of 1961.

The organism is not one which might clog the gills of fish. Two dead fish were examined, and their gills showed no abnormal appearance. The most logical conclusion is that a toxin produced by *Gymnodinium flavum* is the killing agent. Cells of this species, after formalin preservation, give rise to large quantities of long threadlike materials, which tend to be straight, like acicular crystals, but which are flexible and of unknown composition. Nothing comparable has been observed by us for any other dinoflagellate. The crystals were not extruded when the formalin was first applied but appeared within 24 hours. They are strongly reminiscent of certain alkaloids. Should another bloom of this species appear, the nature of these artifacts would be worth investigation.

It is noteworthy that the bloom lasted for a month. Numbers were never comparable to those of some other known dinoflagellate blooms. *Gymnodinium breve*, for example, has attained populations of 20,000/ml or greater, whereas the highest number encountered here was 2676/ml at Point Loma on July 12 in the surface water. If any fish were killed there at this time, they were not noticed. The two small kills observed in Mission Bay were minor. But if huge numbers of the organism built up in the Bay,

which has a small tidal exchange compared to Point Loma, the situation could become quite serious. Altogether, the rarity of the organism in time, its tendency to bloom when it does appear, its probability of being a fish killer, and the peculiar artifacts it yields on formalin preservation indicate that this merits further investigation.

Literature Cited

American Public Health Association. 1960. Standard methods for the examination of water and wastewater. Amer. Public Health Assn., New York, ed. 11, 522 pp.

Barlow, John P., and Richard T. Myren. 1961. Oxygen resources of tidal waters. Water and Sewage Works, vol. 2, pp. 68-71.

Hornell, James. 1917. A new protozoan cause of widespread mortality among marine fishes. Madras Fisheries Bull., no. 11, pp. 53-66.

Hutton, Robert F. 1956. An annotated bibliography of red tides occurring in the marine waters of Florida. Jour. Florida Acad. Sci., vol. 19, pp. 123-146.

Kofoid, Charles Atwood, and Olive Swezy. 1921. The free-living unarmored Dinoflagellata. Univ. Calif. Publ. Zool., Memoirs, no. 5, vii + 562 pp.

Lackey, James B., and Jacqueline A. Hynes. 1955. Engrg. Prog. Univ. Florida, vol. 9, no. 2, pp. 1-24.

U. S. Fish and Wildlife Service. 1961. Industrial wastes account for most fish kills. Commercial Fisheries Review, vol. 23, no. 9, pp. 39-40.

Phelps Laboratory, University of Florida, Gainesville, Florida; Scripps Institution of Oceanography, University of California, La Jolla, California.